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HOBAN project: towards the development of radiation-tolerant fiber-based temperature sensors for nuclear industry

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ABSTRACT

HOBAN (Development of Hard Optical Fiber BrAgg GratiNgs Sensors) is an European H2020 project granted by Kic InnoEnergy and aiming the development of fiber-based temperature and strain monitoring systems that can withstand harsh nuclear environment (350°C temperature and MGy dose levels). The objective will be achieved by employing 'ad hoc' fiber Bragg grating (FBG) sensors and their associated instrumentation system which will bring to the market new tools for optimizing the running and the services in current and future nuclear power plants. We'll present the challenges associated with this project and recent advances at the OFS conference.

Keywords: fiber, Fiber Bragg Grating, temperature sensor, radiation, silica

1. INTRODUCTION

Fiber Bragg Grating (FBG) sensors have been already demonstrated to be efficient for monitoring spatial and time change of temperature and mechanical strain, thanks to the dependence of the Bragg wavelength (λ_B) on such external parameters: $\lambda_B=2n_{eff}\Lambda$, where n_{eff} is the effective index and Λ is the grating period. On one hand, these optical fiber sensors (OFSs) present clear advantages for integration into the nuclear environments (small size, light weight, electromagnetic immunity, explosive and corrosive resistance, combining of sensing element and transmission media, remote measurements, multiplexing and network sensors). On the other hand, they are still rarely used in nuclear industry mainly because commercial-off-the-shelf (COTS) devices are not directly suitable in radiative environments. Indeed, the performances of COTS sensors are degraded by ionizing radiation through Radiation Induced Attenuation (RIA) and Bragg Wavelength Shift (BWS) phenomena. The first compromises the transmission of the encoded information, whereas the second one entails an error on the sensing parameter measurements[1]. Moreover, the radiation can also reduce the peak amplitude, by decreasing the signal-to-noise ratio and degrading the grating performances.

Specific studies are necessary to enhance the resistance of these devices to both radiation and temperature. It was observed that the fiber transmission is less affected by radiation when it is doped with Fluorine[2]. Concerning the FBGs, the radiation-induced BWS strongly depends on several parameters, such as the fiber composition, the conditions of the grating inscription or pre-irradiation treatments[3]. Figure 1 reviews the main parameters that are known to influence the amplitude of the FBG radiation response and that have to be considered during the development phase of a new technology of radiation hardened FBGs. To identify the best FBGs for operation in MGy dose level radiation environment, a deep study on all these parameters has been performed varying, for a given fiber, the different laser inscription techniques, post or pre-treatments or for a given writing procedures, changing the fiber. It is important to notice that the radiation hardness of the fiber itself and of the corresponding FBGs writing in it are not correlated[4], implying to work simultaneously on the radiation hardening of both devices.

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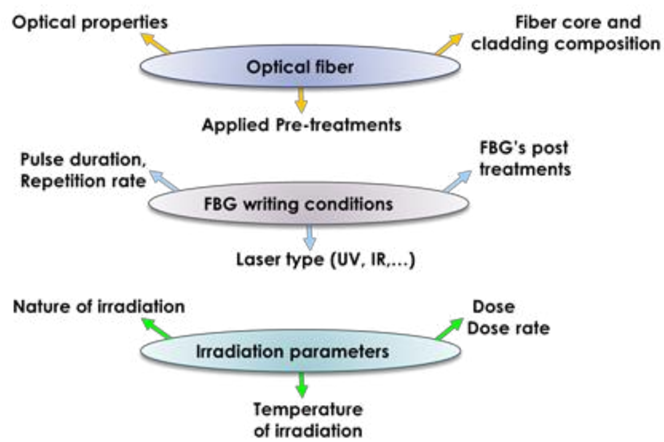

Figure 1. Review of the main extrinsic and extrinsic parameters affecting the FBG radiation response.

Here, we will present the manufacturing procedure of our OFSs and the main results showing their radiation-resistance, the partners involved in this project and their expertise. The strategy to achieve the desired purpose and recent advances will be also illustrated at the OFS conference.

2. RAD HARD FBG WRITING PROCEDURES

Recently, our research group succeeded to elaborate FBGs resistant to harsh environments close to the ones targeted in HOBAN project[5].

First, these radiation-resistant FBGs have to be written in radiation-resistant optical fibers, to avoid that radiation induced attenuation (RIA) phenomenon limits the sensing range of the temperature sensor. For MGy dose levels, it is known that pure-silica core (PSC) and Fluorine-doped fibers are among the most radiation resistant ones. These classes of fibers have been selected for HOBAN investigations. None pre-treatment is applied to the fiber before the FBG inscription to enhance its photosensitivity.

For the writing procedure we provided evidence and patented a procedure ensuring the FBG radiation resistance. A femtosecond laser operating at 800 nm (pulse duration of 50 fs and repetition rate of 1 kHz) was used to write FBGs in both PSC or F-doped optical fibers. Specific laser conditions have to be used to ensure the FBG stability at high temperature, such as a sufficient laser power level[6]. Furthermore, a post treatment is mandatory to stabilize the FBG at high temperatures and we showed that a short thermal annealing pretreatment at high temperature (at 750°C for 15 minutes) permits also to increase the FBG radiation resistance[7].

3. RAD HARD FBG RADIATION RESPONSES

Developed FBGs have been characterized to various radiation constraints. As reported in Fig. 2, we recorded small errors (<1°C) induced on the temperature measurement by irradiation up to 3 MGy dose at temperatures between 25 and 230°C. The presented results pointed out that there are still some ways to improve the radiation hardness of our OFS. For example, it can be seen on Fig.2 that the temperature error is lower during the second run of irradiation (1.5MGy dose) than during the first one (same dose of 1.5MGy). This can be explained by a hardening-by-irradiation effect that was previously investigated by D. Griscom in optical fibers[8].

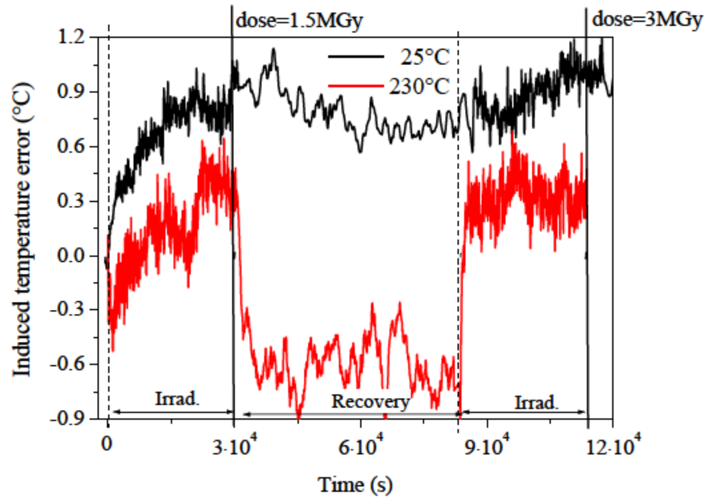

Figure 2. Radiation-induced error on the temperature measurement during irradiation up to 3 MGy at two different temperatures: 25°C and 230°C (figure modified[8]).

Moreover, their radiation-resistance has been also recently tested in a harsher environment, as the core of a real reactor (the low-pressure water-cooled material testing reactor BR2 at SCK-CEN, at Mol in Belgium) and an error on the temperature measurement of only 4°C (BWS of about -40 pm) was observed after a total fast neutron fluence of ~$5 \cdot 10^{19}$ n/cm² and a total gamma-dose of ~5 GGy[9].

4. FROM THE RAD HARD FBG TO THE SENSING SYSTEM

KIC InnoEnergy innovation projects are open to public-private consortia which currently have an innovative technology project and want to convert it into a marketable product[10].Then, an important part of the project, in addition to the rad hard FBG optimization, will be related to the integration of this subcomponent into a fully optimized sensor at the system level. For this, the main expertise of the various research labs of HOBAN will be fruitful.

Areva from Paris La Défense (France) manages the HOBAN project and will participate actively to the qualification tests to ensure the sensor conformity for operations in nuclear environments. iXFiber SAS of Lannion (France) is the optical fiber manufacturing company which will develop both the radiation hardened fibers and the cabling solutions to achieve the final sensor line. SmartFibres Ltd from Bracknell (United Kingdom) will be involved in the FBG integration in the sensor body and in supplying a qualified optical sensor interrogator which have to sustain the environmental conditions. Fraunhofer Institute in Euskirchen (Germany) is responsible of the irradiation tests of the fiber-based device under different conditions, as dose and temperature. The last partner is the Laboratoire Hubert Curien (LabHC UMR CNR5576) of the University of Saint Etienne (France), which will be responsible of the cornerstone of the OFS, i.e. the realization of the rad-hard gratings, their characterization in terms of strain and temperature sensors and ensure the FBG technology transfer to iXFiber.

5. CONCLUSION

In this abstract we presented our Hoban project granted by KIC InnoEnergy Innovation. Five partners from three different countries, Areva from Paris La Défense (France), the iXFiber SAS of Lannion (France) the Smart Fibres Ltd from Bracknell (United Kingdom), the Fraunhofer Institute in Euskirchen (Germany) and the Laboratoire Hubert Curien (LabHC) of Saint Etienne (France), have gathered to develop a COTS temperature and strain OFS resistant to harsh environments characterized by temperatures up to 350°C and/or gamma-doses up to 1 MGy. These characteristics are based on a radiation and temperature hardened FBG, written in radiation resistant fibers with fs-radiation at 800 nm and subjected to a high temperature treatment (750°C) which decreases the grating radiation-sensitivity. Several studies will be performed in the next three years on this OFS to improve its hardness. Development strategy and main challenges will be presented at the conference.

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